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INVESTIGATION OF NATURALLY OCCURRING RADIONUCLIDES IN ROCK, SOILS AND GROUNDWATER SANTA SUSANA FIELD LABORATORY VENTURA COUNTY, CALIFORNIA

June 1, 1990

8640M-77

HDMSP00010149

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INVESTIGATION OF NATURALLY OCCURRING RADIONUCLIDES IN ROCK, SOILS AND GROUNDWATER SANTA SUSANA FIELD LABORATORY VENTURA COUNTY, CALIFORNIA

INTRODUCTION

Pursuant to the request of the Environmental Group, Rocketdyne Division, Rockwell International Corporation, this report presenting the results of the Santa Susana Field Laboratory Facility (the Facility) natural emitters investigation has been prepared. The purpose of the investigation was to identify the naturally occurring sources of low concentrations of radioactivity found in groundwater samples collected during previous investigations at the Facility. This report includes a review and discussion of site specific and regional geologic information pertaining to naturally occurring radioactive elements, a summary of the results of radiochemical analyses performed on site rock, soil and groundwater samples, and recommendations for future radiological monitoring of Facility groundwater.

FACILITY DESCRIPTION AND HISTORY

The Facility is located in the Simi Hills of eastern Ventura County, west of Chatsworth, California (**Figure 1**). The Facility occupies approximately 2,600 acres. There is approximately 700 feet of topographic relief over the entire Facility.

The Facility has been subdivided into administrative areas including Area I, Area II, Area III, Area IV and the Buffer Zone (Figure 1). Areas I and III and the Buffer Zone are owned and operated by Rockwell International Corporation, Rocketdyne Division. Area II is owned by the National Aeronautics and Space Administration (NASA) and operated by the Rocketdyne Division. A portion of Area IV, approximately 90 acres, is optioned to the U.S. Department of Energy (DOE). Many of the facilities in the optioned area are owned by the DOE.

The Facility has operated as a rocket engine testing facility since 1948. Seven major rocket engine test facilities, including Bowl, Canyon, STL-IV, Alfa, Bravo, Coca, and Delta, were in operation simultaneously in the late 1950's and early 1960's (Figure 1). Some of these test areas were phased out of operation in the late 1960's and 1970's. Experimental, small-scale rocket engine testing has taken place at the area now designated APTF (Figure 1). The Alfa, Bravo, Coca, APTF and STL-IV test areas are currently in operation.

Rockwell International Corporation, and its predecessor organizations, have conducted programs for the U. S. Department of Energy (formerly the Atomic Energy Commission and Energy Research and Development Agency) since the early 1950's. The programs have included engineering, research and development and manufacturing functions primarily concerned with nuclear reactor development and applications. During the period 1956 through 1973, SSFL conducted research and development on many nuclear reactor subsystems. In 1966, the Energy Technology Engineering Center (ETEC), also formerly

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known as the Liquid Metal Engineering Center (LMEC), was chartered to provide engineering development and testing of components for the Liquid Metal Fast Breeder Reactor Program. ETEC primarily conducts programs for DOE, and with DOE's approval, other organizations.

Groundwater investigations at the Facility have indicated that the groundwater underlying much of the Facility contains Volatile Organic Compounds (VOCs) in excess of California Department of Health Services Action Levels (DOHS, 1989). It is believed that these VOCs result primarily from solvent flushing activities that took place in conjunction with engine test activities. Rocket engines using hydrocarbon fuel (kerosene) were flushed with trichloroethylene (TCE) before and after testing for removal of residual fuel to prevent explosions. The most prevalent VOC detected in groundwater has been TCE.

A Phase III groundwater investigation was conducted in Area IV of the Facility during July through October 1989. Radiological sampling was performed as part of the Area IV Phase III Investigation. At this time, the investigation of naturally occurring radionuclides was initiated in order to provide information useful for evaluating radiological data generated during the Area IV Phase III investigation and potential future work. The primary objectives of the Phase III investigation were to characterize groundwater quality in the vicinity of suspected-potential contamination source areas as identified by the U.S. Department of Energy (DOE) during May, 1988 (DOE, 1989), and to define hydrogeologic conditions in Area IV.

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During the Phase III investigation, 19 monitor wells were constructed in Area IV.

The results of radiological monitoring conducted as part of the Area IV Phase III Investigation are presented in the *Area IV Radiological Investigation Report, Santa Susana Field Laboratory (Groundwater Resources Consultants, Inc., 1990).* These results indicated that radioactivity in groundwater samples collected from Area IV wells was not elevated and did not exceed background levels determined in groundwater samples collected from other areas of the Facility where no radioactive materials have been used or disposed of. A radiological survey was conducted by Rocketdyne from August 1987 through October 1988 at 25 locations in Area IV suspected to contain residual radioactivity because of the operations performed there or in adjoining facilities. As a result of the survey, Rocketdyne concluded that the 25 Area IV locations do not pose a current hazard to the present occupants, the environment, or neighboring communities (Rockwell, 1988).

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EXECUTIVE SUMMARY

1. The background radiological investigation was conducted in order to characterize naturally occurring radionuclides and to determine background levels of radioactivity in Facility rock, soils and groundwater samples. A literature search was conducted to determine whether the presence of radioactive materials had been documented in geologic formations occurring at the Facility. Rock formation, soil, and groundwater samples were collected and analyzed for radioactivity and a suite of radionuclides known to occur naturally in the environment.

2. The principal geologic formation which underlies most of the Facility is the Chatsworth Formation (**Figure 2**). The Cretaceous Chatsworth Formation is primarily composed of well-consolidated, massively bedded sandstone with well developed fractures and joints. The Chatsworth Formation is overlain by a thin discontinuous layer of Quaternary alluvium, primarily in areas along ephemeral drainages (**Figure 2**).

3. Two main groundwater zones occur at the Facility: A "Shallow Zone" in the surficial alluvium and underlying isolated fractures and zones of weathered sandstone and siltstone of the Chatsworth Formation; and a deeper groundwater system occurring primarily in the fractured Chatsworth Formation. The Shallow

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Zone is discontinuous throughout the Facility. The Chatsworth Formation is the main groundwater zone beneath the Facility. Groundwater flow in the Chatsworth Formation is fracture dominated.

4. The principal groundwater contaminants identified at the Facility are VOCs. Long-term pumping from deep water supply wells has produced substantial water level depressions beneath the central and northeast portions of the Facility. Data collected to date indicates that these water level depressions have prevented off-site movement of degraded groundwater. A large scale groundwater remediation program is currently underway at the Facility. The goal of the remediation program is to reduce VOCs to below the California Department of Health Services action levels (DOHS, 1987).

5. The results of the literature search indicate that studies have not been conducted to document the naturally occurring radionuclides in geologic formations at the site or in the immediate vicinity of the site. However, geologic information reviewed indicates that naturally occuring uranium is frequently associated with carbonaceous material which has been identified in the Chatsworth Formation (Seiden, 1972). This information supports the findings of this study which indicate that uranium occurs naturally in the Chatsworth Formation at the Facility.

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6. Rock and soil samples were collected from nine locations, and groundwater samples were collected from eight monitor wells for determination of naturally occurring radionuclides (Figure 4). Samples were analyzed for gross alpha radioactivity, gross beta radioactivity, gamma emitting radionuclides, radium-226 (^{226}Ra), radium-228 (^{228}Ra), isotopic uranium, isotopic thorium, polonium-210 (^{210}Po), and lead-210 (^{210}Pb). Rock samples were collected from sandstone and siltstone outcrops. Soil samples included sandy silt and sandy clay soils. Groundwater samples were collected from Shallow Zone and Chatsworth Formation monitor wells.

7. The average gross alpha radioactivity determined in sandstone, siltstone and soil samples was 6.36 pCi/g, 7.30 pCi/g and 5.72 pCi/g, respectively (Table 6). The average gross beta radioactivity was 30.8 pCi/g in sandstone samples, 39.2 in siltstone samples and 27.5 pCi/g in soil samples (Table 6). These averages were calculated excluding analytical error.

8. In groundwater samples, gross alpha radioactivity averaged 6.74 pCi/l in filtered samples collected from Shallow Zone wells, and 3.58 pCi/l in filtered samples collected from Chatsworth Formation wells. The average gross beta radioactivity was 3.69 pCi/l in filtered Shallow Zone samples, and 4.72 pCi/l in filtered Chatsworth Formation samples (Table 7). No gamma emitters were detected in groundwater samples (Appendix C).

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9. The predominant natural emitters identified in rock and soil samples were potassium-40 (^{40}K), uranium-238 (^{238}U), uranium-234 (^{234}U) and thorium-232 (^{232}Th) (**Appendix B**). Concentrations of ^{40}K in rock and soil samples ranged from 21.1 ± 2.32 pCi/g to 26.6 ± 2.88 pCi/g (**Table 6**). The mean concentrations of ^{238}U in sandstone, siltstone and soil samples were 1.26 pCi/g, 1.48 pCi/g and 1.10 pCi/g, respectively (**Table 6**). Concentrations of ^{238}U decay products, including ^{234}U, are presented in **Table 6** and **Appendix B**. ^{232}Th in rock and soil samples ranged from 1.14 ± 0.141 pCi/g to 2.03 ± 0.227 pCi/g (**Table 6**).

10. The predominant natural emitters identified in both Shallow Zone and Chatsworth Formation groundwater samples were ^{238}U and ^{234}U. The mean concentrations of ^{238}U and ^{234}U Shallow Zone groundwater samples were 4.23 pCi/l and 4.56 pCi/l, respectively. The mean concentrations of ^{238}U and ^{234}U in Chatsworth Formation groundwater samples were 1.61 pCi/l and 2.00 pCi/l (**Table 7**).

11. The results of groundwater analyses were compared to State and Federal maximum contaminant levels (MCLs) for public drinking water supply. These results were all less than MCLs for radioactivity and specific radionuclides. The sum of concentrations of uranium isotopes was less than the State of California MCL for uranium in all groundwater collected.

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GEOLOGY

The Facility is located in the Simi Hills of eastern Ventura County, California (Figure 1). The Simi Hills are in the central part of the Transverse Range geomorphic province and separate the Simi Valley from the western part of the San Fernando Valley. The Simi Valley is a broad synclinal depression and the Simi Hills form the southern flank of the syncline. A syncline is defined as a fold in rocks in which the strata dip inward from both sides toward the axis (American Geological Institute, 1976).

The Simi Hills are composed primarily of exposures of the Upper Cretaceous Chatsworth Formation (Colburn and others, 1981). This formation is a marine turbidite (sediment deposited from a turbidity current) sequence composed of turbidite sandstone with interbedded shales and minor conglomeratic lenses. The exposure of the Chatsworth Formation in the Simi Hills is characterized by massive, cliff-forming sandstone beds.

The Chatsworth Formation is at least 6,000 feet thick at its designated type location in Woolsey and Black Canyons east of the Facility (Colburn and others, 1981). The depositional base of the Chatsworth Formation is not exposed in the vicinity of the Facility.

The principal geologic units at the Facility are the Chatsworth Formation and the shallow alluvium which overlies the Chatsworth Formation

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in some parts of the Facility (**Figure 2**). The Martinez Formation is exposed in the southwestern portion of the Facility and the Topanga Formation is exposed in the extreme southeastern portion of the buffer zone (**Figure 2**).

CHATSWORTH FORMATION

The Upper Cretaceous Chatsworth Formation underlies most of the Facility. It is composed primarily of well-consolidated, massively bedded sandstone (Facies A) with interbeds of siltstone and claystone (Facies B). The sandstone portion of the formation is primarily an arkosic sandstone with carbonate cement. Arkosic sandstone is sandstone containing 25 percent or more feldspare (American Geologic Institute, 1976).

At the Facility, Chatsworth Formation beds dip to the northwest at approximately 20 to 30 degrees. Well developed fractures and joints are seen in Chatsworth Formation outcrops. To the northwest of the Facility, the Chatsworth Formation is overlain by the Paleocene Martinez Formation (Figure 2).

MARTINEZ AND TOPANGA FORMATIONS

The Topanga Formation of Tertiary age is exposed to the southeast of the Facility (**Figure 2**). It is composed of bedded marine sandstone with a basal conglomerate. The Topanga Formation is younger than the Martinez and Chatsworth Formations.

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The Tertiary Martinez Formation is exposed to the north and northwest of the Facility and in the portion of the facility south of Burro Flats (Figure 4). The Martinez Formation is younger than the Chatsworth Formation and is composed of bedded marine sandstones and shales with a basal conglomerate. The Martinez Formation to the north of the facility dips to the northwest at approximately 30 to 35 degrees. The Martinez Formation weathers to form slopes.

ALLUVIUM

The Chatsworth Formation and the Martinez Formation are overlain by a discontinuous layer of thin Quaternary alluvium, most notably in Burro Flats and along ephemeral drainages (Figure 2). The Quaternary alluvium consists of mixtures of unconsolidated sand, silt, and clay. Drill hole data indicates that in some areas, the alluvium may be as thick as 20 feet. The alluvium is underlain in some places by a zone of Chatsworth Formation which has been weathered in place.

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GROUNDWATER

Hydrogeologic conditions at the Facility have been evaluated based on data compiled from approximately 150 monitor and 13 water supply wells, and surficial geologic conditions including fracture characteristics and occurrence. Site-wide hydrogeologic conditions were previously described in detail in the *Groundwater Monitoring Annual Report (Groundwater Resources Consultants, Inc., 1989a)* and the *Hydrogeological Assessment Report (Groundwater Resources Consultants, Inc., 1987)*. Hydrogeologic conditions specific to Area IV were described in the *Phase III Report, Investigation of Groundwater Conditions, Santa Susana Field Laboratory - Area IV (Groundwater Resources Consultants, Inc., 1989b)*.

Results of previous investigations have indicated the presence of two groundwater zones beneath the Facility; (1) a shallow groundwater system in the surficial alluvium and the underlying zones of weathered sandstone and siltstone, and isolated shallow fracture systems, and (2) a deeper groundwater system in the fractured Chatsworth Formation. In some parts of the Facility the two systems appear to be hydraulically connected.

SHALLOW ZONE

The Shallow Zone is composed primarily of unconsolidated sand, silt, and clay which has been eroded from the surrounding Chatsworth and Martinez

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Formations. Also included in the Shallow Zone hydrogeologic unit is the underlying weathered portion of the Chatsworth Formation.

Water level data from Shallow Zone wells indicate that the surface of the saturated portion of the Shallow Zone is, in general, a subdued expression of the topographic surface. Water in the Shallow Zone primarily moves laterally and also downward into the underlying Chatsworth Formation.

CHATSWORTH FORMATION

The principal water bearing unit at the Facility is the Chatsworth Formation. The Chatsworth Formation is composed of well-consolidated massive sandstone with interbeds of siltstone and claystone. The groundwater flow in the Chatsworth Formation may be described as fracture dominated as the occurrence and movement of groundwater are primarily controlled by the location and orientation of fractures. The Chatsworth Formation fracture systems are associated with bedding planes, jointing, and faulting. The overall permeability of the Chatsworth Formation is considered to be very low except along open fractures.

HISTORIC USE OF GROUNDWATER/GROUNDWATER MOVEMENT

The water supply wells constructed by Rocketdyne in the early to mid-1950's to satisfy industrial water demands range in depth from 203 to 2,304 feet (Table 2, Figure 1). Groundwater withdrawals from WS wells over the

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period of time from 1948 to the present have caused significant water level declines at the Facility. Water levels at many of the wells declined in excess of 150 feet during the peak-use years in the late 1950's and early 1960's.

Long term pumping has exerted considerable control over the movement of groundwater, and therefore the migration of contaminants. Water level contours representing recent water levels measured in wells completed in the Chatsworth Formation groundwater system are presented on Figure 3.

Current water level contours indicate that groundwater occurring in the central and northeast portion of the Facility appears to be migrating toward the pumping depression which has been maintained in the northeast quarter of the Facility since the late 1950's (Figure 3). Nineteen Chatsworth Formation wells and two Shallow Zone wells were constructed at the Facility in July and August, 1989. Water level data obtained from these wells were used to further characterize groundwater movement and to determine the location of a groundwater divide in the vicinity of Area IV. Water level elevations indicate that a west to northwesterly component of groundwater flow exists in Area IV. Water level contours indicate a southerly component of groundwater flow in the southwest portion of the Facility. Groundwater elevation contours and lateral direction of flow are illustrated on Figure 3.

It is believed that the long term groundwater withdrawals and the resulting water level depression beneath the central and northeast portions

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of the Facility have served to limit the potential for the off-site movement of degraded groundwater. To date, there is no indication from groundwater quality data collected from off-site wells and springs that degraded groundwater has migrated beyond the property boundary. Rocketdyne has proposed to construct two additional monitor wells located off-site of Area IV near the northwest Facility boundary.

There are seven extraction/treatment systems currently in place at the Facility: the Alfa, Bravo, Canyon, Delta, Bowl, STL-IV, and RD-9 Area systems. In addition, there is an extraction system located at the ECL area. Groundwater extracted from the ECL area will be conveyed to the RD-9 area treatment system. The location of each system is shown on Figure 3. The extraction/treatment systems are designed to remove VOCs from groundwater. Each system is designed to reduce existing organic contaminants to below the California Department of Health Services Action Levels (DOHS, 1989).

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LITERATURE REVIEW

A literature search was conducted to determine if naturally occurring radioactive elements and isotopes have been documented in geological formations present at the Facility, or correlative formations in Ventura County. A list of publications reviewed and telephone conversations conducted is presented in **Appendix A.**

The results of the literature search indicate that naturally occurring radioactive materials have not been previously reported at the site, nor in the geologic formations occurring at or in the immediate vicinity of the site. Radioactive materials have been reported elsewhere in Ventura County, primarily in the Grimes Canyon area (about 15 miles northwest of the Facility) and in the Ojai area (about 35 miles northwest of the Facility). In these areas, naturally occurring radioactive materials are found in either the Eocene Matilija and Coldwater Formations, the Upper Eocene to Lower Miocene Sespe Formation, the Miocene Rincon Shale and Monterey Formation, and the Pliocene Quatal Formation. Across the county line, in Los Angeles County, radioactive materials have been reported in the Pliocene to Pleistocine Sangus Formation. None of these formations are present at the Facility.

Radioactive materials documented in the Sespe Formation located off-site are found in clastic material derived from volcanic and granitic rock. Clastic materials are fragments of rock or organic structures that have been

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moved individually from their place of origin. In the Sespe Formation, clastic material was leached by surface and groundwater to provide the uranium for deposits (Conrad, 1949, Cooper, 1953, Dickinson, 1982, Dickinson and Leventhall, 1988, Dickinson et al, 1984, Finch, 1967, Gianella, 1928, Troxel et al, 1957, Weber et al, 1973).

Uranium is commonly associated with carbon rich and carbonaceous material, particularly in Eocene sedimentary rocks. The carbonaceous material acts as a scavenger or absorbent for these materials. Investigations conducted in the area of the Facility report charcoal, burnt wood and carbonaceous matter in Cretaceous ("Chico" or Chatsworth Formation), and Paleocene (Las Virgenes sandstone member, Martinez Formation equivalent) rocks (Dickinson and Leventhal, 1989, Moore and Stephens, 1954, Seiden, 1972 and Troxel et al, 1957). The "Chico" Formation was an earlier, informal designation of the Chatsworth Formation. A report describing an area about 3-5 miles north of the Facility reports that the Cretaceous "Chico" Formation has carbonaceous matter throughout (Seiden, 1972). The carbonaceous material could be likely sources for naturally occurring radioactive materials present at the site.

One report reviewed indicates that uranium and other trace metals have been found in crude oils in California in Miocene rocks (Fantozzi, 1955). This might be a possible source of naturally occurring radioactive materials if any hydrocarbons are present beneath the site. Uranium complexes with hydrocarbons. Where oxygenated groundwaters penetrate petroleum reservoirs,

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severe alteration of the petroleum takes place and uranium can be mobilized and transported within the groundwater system (Durrance, 1986).

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METHODS OF INVESTIGATION

Eight monitor wells were sampled and soil and rock samples were collected from nine locations for determination of naturally occurring radionuclides at the Facility. Descriptions of samples collected, sample locations, dates sampled and analytical parameters are presented in Table 1 for rock and soil samples, and in Table 2 for groundwater samples. Analytical methods are describe in Table 3. Sample locations are shown on Figure 4.

SAMPLE LOCATIONS

Groundwater samples were collected from three Shallow Zone wells, SH-11, RS-5 and RS-28, and from five Chatsworth Formation wells, RD-6, RD-14, WS-13, OS-16 and OS-21. Wells OS-16 and OS-21 are off-site wells located east and west of the Facility boundaries, respectively (Figure 1, Figure 4).

Several criteria were utilized in selecting monitor wells for determination of natural emitters in groundwater. Most of the wells sampled are located in areas and downgradient of areas at the Facility where nuclear activities have not been conducted. One Shallow Zone well, RS-28, and one Chatsworth Formation well, RD-14, are located in Area IV. Background information obtained from samples collected from these wells will be compared to

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other areas of the Facility and radioactivity data collected from other Area IV wells.

Groundwater samples collected from Shallow Zone well SH-11 are typical of samples collected from wells constructed in shallow alluvial deposits at the Facility. The low yield of these wells does not permit sufficient development to reduce the amount of sediments in water samples. Unfiltered samples with high sediment content have characteristically higher radioactivity than filtered samples collected from the same well. Unfiltered samples were collected from Shallow Zone and Chatsworth Formation wells to determine the contribution of naturally occurring radionuclides in sample sediments to the overall radioactivity of the sample.

A total of seven rock and three soil samples were collected at the Facility for determination of naturally occurring radionuclides. Sample locations for natural emitters (NE) one through nine are described in Table 1 and are shown on Figure 4. Rock samples included four sandstone samples (NE-1, NE-5, NE-6, and NE-8) and three siltstone samples (NE-4, NE-7 and NE-7A). One siltstone sample, NE-7A, was collected adjacent to another siltstone sample, NE-7, in order to approximate a sample duplicate. Of the three soil samples, two sandy silt samples were collected, NE-3 and NE-9, and one sandy clay sample, NE-2.

One soil and one sandstone sample were collected in Area IV of the Facility. The remaining samples were collected throughout Areas I, II, and III of the Facility, the Buffer Zone and off-site (Figure 4). Nuclear

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activities have not been conducted in these areas. A description of rock and soil samples collected and sample locations is provided in Table 1.

Analytical Parameters

Analytical methods are described for each sample parameter in Table 3. All samples were screened for gross alpha and gross beta radioactivity, and gamma radiation. In addition, specific analyses were performed for determination of ^{226}Ra, ^{228}Ra, uranium isotopes, thorium isotopes, ^{210}Po and ^{210}Pb. The list of analytical parameters was developed in conjunction with recommendations by United States Testing Company, Inc. for commonly occurring natural radionuclides in the environment.

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ANALYTICAL RESULTS

The analytical results for samples collected during the background radiological investigation are presented in **Appendices B** and **C**. Gross alpha and gross beta radioactivity results are summarized in **Tables 4** and **5**, and for groundwater samples are shown on **Figure 4**. The mean and range of concentration of gross alpha and beta radioactivity and specific radionuclides are presented in **Table 6** for rock and soil samples, and in **Table 7** for groundwater samples.

BEDROCK AND SOIL SAMPLES

Seven rock samples were collected. Of these, four were sandstone (NE-1, NE-5, NE-6, and NE-8) and three were siltstone (NE-4, NE-7 and NE-7A). Sample locations are shown on **Figure 4**. Gross alpha radioactivity in sandstone samples ranged from 3.93 ± 2.23 picocuries per gram (pCi/g) at NE-5 to 8.60 ± 3.27 pCi/g at NE-8. Gross alpha radioactivity in siltstone samples ranged from 4.84 ± 2.40 pCi/g at NE-4 to 9.01 ± 3.27 pCi/g at NE-7 (**Table 4, Figure 4**). The average gross alpha radioactivity in sandstone and siltstone samples was 6.36 pCi/g and 7.30 pCi/g, respectively (**Table 6**). Gross beta radioactivity ranged from 28.6 ± 4.61 pCi/g at NE-8 to 33.3 ± 5.21 pCi/g at NE-6 in sandstone samples, and from 38.2 ± 5.63 pCi/g at NE-7A to 39.8 ± 5.81 pCi/g at NE-7 in siltstone samples. The average gross beta radioactivity of sandstone samples was 30.8 pCi/g. The average gross beta radioactivity of siltstone samples was 39.2 (**Table 6**).

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Three soil samples were collected during the natural emitters investigation. Samples NE-2, NE-3 and NE-9, were sandy silt soils. The NE-2 sample was a sandy clay soil.

Gross alpha radioactivity in soil samples ranged from 4.43 ± 2.43 pCi/g in the sandy silt sample collected at NE-9 to 7.24 ± 3.08 pCi/g in the sandy clay sample collected at NE-2. The results for gross beta radioactivity ranged from 24.7 ± 4.18 pCi/g in the sandy silt soil sample collected at NE-9 to 27.0 ± 4.46 pCi/g in the sandy clay soil collected at NE-2 (Table 6, Appendix B). The mean gross alpha and gross beta radioactivities of the three soil samples were 5.72 pCi/g and 26.53 pCi/g, respectively (Table 6).

The predominant natural emitters identified in rock and soil samples collected at the Facility include ^{40}K, ^{238}U, ^{234}U and other ^{238}U decay products, and ^{232}Th and its decay products. ^{40}K concentrations ranged from 24.7 ± 2.81 pCi/g to 26.6 ± 2.88 pCi/g in siltstone samples, and from 21.4 ± 2.41 pCi/g to 26.5 ± 2.92 pCi/g in sandstone samples (Appendix B, Table 6). The average concentration of ^{40}K in sandstone samples was 24.2 pCi/g. The average concentration of ^{40}K in siltstone samples was 25.9 pCi/g (Table 6). In soil samples, ^{40}K concentrations ranged from 21.1 ± 2.32 pCi/g to 23.5 ± 2.78 pCi/g (Appendix B, Table 6). The average soil concentration of ^{40}K was 22.2 pCi/g (Table 6).

The concentrations of ^{238}U in sandstone ranged from 0.830 ± 0.122 pCi/g in a sample collected at NE-8 to 1.53 ± 0.206 pCi/g in a sample collected at NE-1. Siltstone concentrations of ^{238}U ranged from 1.29 ± 0.177 pCi/l in

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a sample collected at NE-7 to 1.74 ± 0.219 pCi/l in an adjacent sample collected at NE-7 (Appendix C). The mean values of ^{238}U in sandstone and siltstone samples were 1.26 pCi/g and 1.48 pCi/g, respectively (Table 6). ^{238}U decay products ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, and ^{210}Po were also detected in sandstone and siltstone samples. The mean concentrations of ^{234}U in sandstone samples was 1.26 pci/g. The mean concentration of ^{234}U in siltstone samples was 1.36 pCi/g (Table 6). Concentrations of ^{230}Th, ^{210}Po and ^{210}Pb detected in rock samples are presented in Appendix B.

In soils samples, the concentrations of ^{238}U were reported at 0.771 ± 0.118 pCi/g in the sandy clay soil collected at NE-2, and 1.29 ± 0.175 pCi/g and 1.25 ± 0.180 pCi/g in sandy silt soil samples collected at NE-3 and NE-9, respectively. The mean concentration of ^{238}U in soil samples was 1.10 pCi/g. The mean concentration of ^{234}U in soil samples was also 1.10 pCi/g. The ^{238}U decay series products, ^{230}Th, ^{210}Pb and ^{210}Po, were also detected in soil samples (Appendix B). In general, concentrations of those decay products were lower in the sandy clay sample collected at NE-2 than in the two sandy silt samples collected at NE-3 and NE-9 (Appendix B).

In addition to ^{40}K, ^{238}U, and ^{234}U, ^{232}Th and one of its decay products thorium-228 (^{228}Th) were found to be abundant in both rock and soil samples. In sandstone samples, ^{232}Th concentrations ranged from 1.14 ± 0.141 pCi/g to 1.62 ± 0.186 pCi/g at NE-6 and NE-8, respectively (Appendix B). ^{232}Th concentrations ranged from 1.18 ± 0.174 pCi/g at NE-7A to 2.28 pCi/g at NE-4 in siltstone samples (Appendix B). The mean concentration of ^{232}Th in sandstone and siltstone samples was 1.35 pCi/g and 1.70 pCi/g, respectively

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(Table 6). Concentrations in rock samples of naturally occurring ^{228}Th, a daughter product of ^{232}Th, are presented in Appendix B.

In sandy silt soils, ^{232}Th was reported in concentrations of 1.45 ± 0.169 pCi/g in the sample collected at NE-3, and at 2.03 ± 0.227 pCi/g in the sample collected at NE-9 (Appendix B). ^{232}Th was reported at 1.50 ± 0.174 in the sandy clay soil sample collected at NE-2 (Appendix B). The average concentration of ^{232}Th in the three soil samples was 1.66 pCi/g (Table 6).

The following discussion includes analytical results for filtered groundwater samples only. The results of analyses for radioactivity and radionuclides in unfiltered samples are presented in Appendix C. In general, additional radioactive components identified in unfiltered samples are the same as those identified in rock and soil samples, with the exception of ^{40}K. ^{40}K was not considered to be a significant contributor to radioactivity in groundwater samples. The abundance of K in groundwater samples collected at the Facility is low. Furthermore, ^{40}K is a weak beta emitter.

GROUNDWATER

Groundwater samples were collected from three Shallow Zone wells and five Chatsworth Formation wells for determination of natural emitters. All groundwater samples were analyzed for gross alpha and gross beta radioactivity, gamma emitting radionuclides, ^{226}Ra, ^{228}Ra, isotopic uranium,

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isotopic thorium, ^{210}Pb, and ^{210}Pb. The results of these analyses are presented in **Appendix C**. The results of analyses for gross alpha and gross beta radioactivity are summarized on **Table 5**. The concentration ranges and means for gross alpha and beta radioactivity and radioisotopes detected in groundwater samples are presented in **Table 7**.

Shallow Zone

Gross alpha radioactivity in Shallow Zone wells ranged from 4.62 ± 2.59 pCi/l reported in a filtered sample collected from well RS-28 on November 1, 1989 to 9.57 ± 5.05 pCi/l in a filtered sample collected from well SH-11 on October 31, 1989 (**Appendix C**). The mean gross alpha radioactivity of samples collected from Shallow Zone wells was 6.74 pCil/l (**Table 6**).

The reported gross beta radioactivity in filtered samples collected from Shallow Zone wells ranged from 2.43 ± 1.68 pCi/l at well SH-11 to 5.30 ± 2.80 pCi/l at well RS-5. The average gross beta radioactivity in filtered samples collected from Shallow Zone wells was 3.69 pCi/l (**Table 7**).

Samples collected from Shallow Zone wells were analyzed for ^{226}Ra and ^{228}Ra. ^{226}Ra is a decay product of ^{238}U. ^{228}Ra is a decay product of ^{232}Th. The mean concentrations of ^{226}Ra and ^{228}Ra in filtered samples colleted from Shallow Zone wells were 0.0957 pCi/l and 0.896 pCi/l, respectively (**Table 7**).

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Other analyses performed on groundwater samples collected from Shallow Zone wells included gamma radiation, isotopic uranium, isotopic thorium, ^{210}Po and ^{210}Pb. No gamma emitting radionuclides were detected by gamma scan (Appendix C). ^{238}U and ^{234}U, were found to be the predominant alpha emitters. The mean ^{238}U concentration in Shallow Zone wells was 4.23 pCi/l. The mean ^{234}U concentration was 4.56 pCi/l (Table 7). ^{210}Pb was not detected in any of the filtered Shallow Zone groundwater samples. ^{210}Po was detected in concentrations ranging from 0.0320 ± 0.0187 pCi/l in a filtered sample collected from well RS-28 to 0.175 ± 0.0486 pCi/l in a filtered sampled collected from well SH-11 (Appendix C).

Chatsworth Formation

Gross alpha radioactivity in filtered samples collected from Chatsworth Formation wells ranged from 1.08 ± 1.56 pCi/l in a sample collected from off-site well OS-21 on October 19, 1989 to 5.54 ± 2.72 pCi/l in a sample collected on the same date from off-site well OS-16 (Table 5). The mean gross alpha radioactivity in filtered Chatsworth Formation groundwater samples was 3.58 pCi/l (Table 7).

The reported gross beta radioactivity in filtered Chatsworth Formation groundwater samples ranged from 1.97 ± 1.65 pCi/l in a sample collected at well RD-14 on October 18, 1989 to 6.99 ± 2.72 pCi/l in the duplicate sample collected at off-site well OS-16 on November 1, 1989 (Table 5). The mean beta radioactivity in filtered Chatsworth Formation wells was 4.72 pCi/l (Table 7).

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The mean concentrations of ^{226}Ra and ^{228}Ra in filtered samples collected from Chatsworth Formation wells were 0.789 pCi/l and 1.525 pCi/l, respectively (Table 7). No gamma emitters were detected in any of the samples collected from Chatsworth Formation wells (Appendix C).

Natural ^{238}U and ^{234}U were the predominant radioisotopes detected in filtered samples collected from Chatsworth Formation wells. The mean concentrations of ^{238}U and ^{234}U were 1.61 pCi/l and 2.00 pCi/l, respectively (Table 7). Small quantities of ^{210}Pb and ^{210}Po, components of the ^{238}U decay series, were detected in Chatsworth Formation samples (Appendix C). Thorium isotopes were not detected in filtered groundwater samples collected from Chatsworth Formation wells (Appendix C).

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DISCUSSION OF ANALYTICAL RESULTS

The analytical results of the natural emitters investigation indicate the presence of naturally occurring radioisotopes in rock, soil and groundwater samples collected at the Facility. Potassium, uranium and thorium, and the decay products of uranium and thorium, were the predominant natural emitters identified in rock and soil samples. Uranium and its decay products were the predominant natural emitters identified in groundwater samples.

Concentrations of radioactivity and natural radionuclides varied little between rock and soil types. The average gross alpha radioactivity in sandstone, siltstone, and soil samples was 6.36 pCi/g, 7.30 pCi/g and 5.72 pCi/g, respectively. The average gross beta radioactivity in these samples was 30.8 pCi/g, 39.2 pCi/g and 26.5 pCi/g, respectively.

In soil and rock samples, measured gross alpha radioactivity is accounted for by activity of ^{238}U and ^{232}Th series alpha emitters (Appendix B). Measured gross beta radioactivity is for the most part attributable to detected concentrations of the beta emitter ^{40}K (Appendix B).

Average radioactivity was also determined in groundwater samples. Alpha radioactivity was slightly higher in filtered Shallow Zone groundwater samples than in filtered Chatsworth Formation groundwater samples. The average gross alpha and gross beta radioactivities of filtered Shallow Zone

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groundwater samples were 6.74 pCi/l and 3.69 pCi/l, respectively. The average gross alpha and gross beta radioactivities of Chatsworth Formation groundwater samples were similar at 3.58 pCi/l and 4.72 pCi/l, respectively.

DRINKING WATER STANDARDS

Maximum Contaminant Levels (MCLs) have been established for monitoring radioactivity in drinking water supplied by public water systems by federal and California state regulations (40 CFR 141, CCR 22). The combined ^{226}Ra and ^{228}Ra MCL is 5 pCi/l. The MCL for gross alpha particle activity, including ^{226}Ra but excluding radon and uranium, is 15 pCi/l. In addition, the State of California has established a 20 pCi/l MCL for uranium (CCR 22).

Water systems with greater than 30,000 service connections and using surface water sources are also required to monitor their water supplies for tritium, strontium-90 (^{90}Sr) and gross beta particle activity. The maximum exposure established for manmade radionuclides in drinking water is an annual dose equivalent of four millirems per year. Compliance with this requirement is assumed if the average gross beta particle activity is less than 50 pCi/l, and if the average concentrations of tritium and ^{90}Sr are less than 20,000 pCi/l and 8 pCi/l, respectively (40 CFR 141, CCR22).

Although groundwater occurring at the Facility is not used for drinking water, none of the Chatsworth Formation groundwater samples collected during the natural emitters investigation exceeded drinking water MCLs for radiological parameters. Combined ^{226}Ra and ^{228}Ra concentrations were less than

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5 pCi/l, and gross alpha radioactivity was less than 15 pCi/l in all samples.

Reported concentrations of gross beta radioactivity were well below the 50 pCi/l MCL in all groundwater samples. Moreover, beta radioactivity in all groundwater samples was less than the 8 pCi/l MCL for ^{90}Sr. Thus, although groundwater samples were not specifically tested for ^{90}Sr, it would be reasonable to assume that the concentration of ^{90}Sr in groundwater samples did not exceed the MCL for ^{90}Sr.

During the period of June through October 1989, 114 samples were collected from 61 wells throughout the Facility for analysis of tritium. Tritium concentrations did not exceed the 20,000 pCi/l drinking water standard in any of the 114 samples collected. The highest concentration of tritium detected in groundwater during the June through October 1989 sampling period was 699 ± 236 pCi/l. Tritium was determined to be less than the laboratory detection limit or reported overall laboratory error in all samples collected from off-site wells, and in 93 of 97 samples collected from 51 wells located on-site. (Groundwater Resources Consultants, Inc., 1990).

SAMPLE VARIABILITY

The overall laboratory uncertainty associated with gross alpha radioactivity ranged from 36 to 55 percent in soil and rock samples, and from 30 to 134 percent in groundwater samples (Table 8). The overall laboratory

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uncertainty associated with gross beta measurements ranged from 15 to 17 percent in soil and rock samples, and from 36 to 84 percent in groundwater samples. Average radioactivity values reported in Tables 6 and 7 do not include analytical uncertainty or sampling variability.

The sampling variability due to field handling methods was not calculated due to the small sample size. Precision for a single sampling event was determined for gross alpha and gross beta radioactivity using sample duplicates. Overall precision defined in terms of relative percent difference was calculated for soil and groundwater samples. This data is presented in Table 8.

The relative percent difference for gross alpha radioactivity and gross beta radioactivity in soil sample duplicates NE-7 and NE-7A (adjacent samples) was 11 and 4 percent, respectively. The relative percent difference for gross alpha radioactivity in groundwater sample duplicates collected from WS-13 was 30 percent, and 8 percent and 45 percent for groundwater sample duplicates collected from OS-16 on October 19 and November 1, respectively. Relative percent difference for gross beta radioactivity was 2 percent for groundwater samples collected from well WS-13, and 17 and 4 percent for 2 sets of duplicates collected from well OS-16 (Table 8).

ROCK FORMATION AND SOIL NATURAL EMITTERS

Natural emitters identified in background rock and soil samples included potassium, uranium and thorium. Uranium and thorium, with their

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daughter products, are recognized as the two main sources of natural radiation (Durrance, 1986). Usually present in small quantities, these elements are widely distributed in rock and mineral deposits. The most predominant of the natural emitters identified in rock and soil samples in terms of activity is potassium, which is the seventh most abundant element in the earth's crust. Although potassium is a much weaker source of radiation than the uranium or thorium series, because it is so abundant it is found to be an equal contributor to uranium and thorium in terms of natural radiation (Durrance, 1986).

Potassium

The average concentration of ^{40}K in sandstone, siltstone and soil samples collected during the natural emitters investigation was 24.2 pCi/g, 25.9 pci/g and 22.2 pCi/g, respectively (Table 6).

^{40}K is naturally occurring and is the only radioactive isotope of potassium. ^{40}K accounts for 0.0119 percent of total potassium. The half-life of ^{40}K is 1.31×10^9 years. ^{40}K decays by beta emission and electron capture, and emits a single gamma ray at 1.46 MeV following electron capture. Typical levels of ^{40}K in sandstone is about 1.3 parts per million (21.5 pCi/g) (Durrance, 1986).

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Uranium

The predominant isotopes of uranium detected in rock and soil samples were ^{238}U, and the ^{238}U decay product, ^{234}U. The average concentration of ^{238}U reported in sandstone, siltstone and soil samples was 1.26 pCi/g, 1.48 pCi/g and 1.10 pCi/g, respectively. The average concentration of ^{234}U detected in sandstone, siltstone and soil samples was 1.26 pCi/g, 1.36 pCi/g and 1.10 pCi/g.

Other ^{238}U decay series isotopes detected in rock and soil samples included ^{230}Th, ^{226}Ra, ^{214}Pb, ^{210}Pb and ^{210}Po. Low concentrations of ^{235}U were detected in rock and soil samples ranging from 0.0201 ± 0.0166 pCi/g in sandstone sample NE-8 to 0.0936 ± 0.0339 pCi/g in sandstone sample NE-5 (Appendix B).

Uranium is naturally occurring and is distributed ubiquitously throughout the earth's crust. The average abundance of uranium in the earth's crust is about 2.7 ppm (Durrance, 1986). Uranium occurs as a common trace element in most rock types (Hess et. al., 1985). The typical range of uranium in sandstone is 0.5 to 4 ppm (0.34 pCi/g to 2.68 pCi/g). The uranium content of soils is usually about one ppm (0.67 pCi/g), but can be as high as eight ppm (5.36 pCi/g) (Durrance, 1986).

Three isotopes of uranium occur naturally, ^{238}U, ^{234}U and ^{235}U. Two of these, ^{238}U and ^{235}U, are parents of series that end in stable lead isotopes. ^{234}U is a daughter product of the ^{238}U decay series. The half-lives of ^{238}U,

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^{234}U and ^{235}U are 4.468 X 10^9 years, 2.48 X 10^5 years and 7.13 X 10^8 years, respectively (Durrance, 1986). The distribution of natural uranium isotopes on a weight basis is 99.27 percent uranium-238, 0.72 percent uranium-235, and 0.006 percent uranium-234 (Cothern and Lappenbusch, 1983). In equilibrium, this results in relative activities of 1, 0.046 and 1, respectively.

In the geologic environment, uranium is generally present in either the U^{4+} or the U^{6+} oxidation state. Uranium compounds in the tetravalent state are mostly insoluble, and are readily oxidized to the more stable hexavalent state (U^{6+}) as the uranyl ion $(UO_2)^{2+}$ (Cothern and Lappenbusch, 1983). Uranyl ions can be readily absorbed on clay minerals, organic matter, and readily form many complexes with anions ordinarily found in soil-water environments such as carbonate, sulfate and fluoride. Oxidation-reduction conditions and pH are important parameters of uranium mobilization and immobilization in rocks and soil (Durrance, 1986).

Thorium

Thorium is a major contributor to natural terrestrial radioactivity (Bowie & Plant, 1983). The average concentration of ^{232}Th reported in sandstone, siltstone and soil samples collected during the natural emitters investigation was 1.35 pCi/g, 1.70 pCi/g and 1.66 pCi/g, respectively.

Thorium has only one oxidation state, Th^{4+}, and is generally very insoluble in water. ^{232}Th is the principal isotope of thorium, the half-life of ^{232}Th is 1.39 X 10^{10} years. ^{232}Th decay products detected in rock and

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soil samples collected during the natural emitters investigation included ^{228}Ra, ^{228}Th and ^{212}Pb.

The content of thorium in sandstone is typically 1 ppm, except where concentrations of heavy minerals occur. Arkose sands have an average of about 5 ppm of thorium (Durrance, 1986). Soils in general contain around 10 ppm of thorium (Bowie and Plant, 1983).

GROUNDWATER NATURAL EMITTERS

The predominant naturally occurring radioisotopes in groundwater samples were ^{238}U and ^{234}U. Other radioisotopes of the ^{238}U decay series, and ^{228}Ra, were detected in groundwater samples in low concentrations (**Appendix C**).

Uranium

Average concentrations of ^{238}U and ^{234}U in Shallow Zone groundwater samples were 4.23 pCi/l and 4.56 pCi/l, respectively. Concentrations of ^{238}U and ^{234}U averaged 1.61 pCi/l and 2.00 pCi/l in Chatsworth Formation groundwater samples (**Table 7**).

The natural occurrence of uranium in water depends on factors such as the uranium concentration in the host rock, the presence of oxygen and complexing agents, the pH and the nature of contact between the uranium minerals and water (Hess et.al., 1985). The average concentration of

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uranium in U.S. groundwaters is 3 pCi/l (Cothern and Lappenbusch, 1983). The MCL for natural uranium established by the California Department of Health Services for drinking water is 20 pCi/l. The total concentration of uranium isotopes in groundwater samples collected at the Facility during the natural emitters investigation were all well below the suggested action level.

Radium

The mean concentrations of ^{226}Ra and ^{228}Ra in Shallow Zone groundwater samples were 0.0857 pCi/l and 0.896 pCi/l, respectively. The mean concentration of ^{226}Ra in Chatsworth Formation samples was 0.789 pCi/l, and the mean concentration of ^{228}Ra in Chatsworth Formation samples was 1.525 pCi/l.

^{226}Ra and ^{228}Ra are components of the ^{238}U and ^{232}Th decay series, respectively. Both ^{226}Ra and ^{228}Ra are natural isotopes of radium. ^{226}Ra is an alpha emitter with a half-life of 1,622 years. Directly generated by ^{232}Th decay, ^{228}Ra is a shorter-lived, weak beta emitter with a half-life of 5.7 years (Hess et.al., 1985).

The distribution of ^{226}Ra and ^{228}Ra in water is a function of the uranium and thorium content of the aquifer, geochemical processes within the aquifer and the half-life of each isotope. The estimated average activity ratio of thorium to uranium in the earth's crust is 1.2 - 1.5. Thus, in the absence of enrichment or depletion processes, ^{228}Ra activity should be higher than ^{226}Ra activity (Hess et.al., 1985).

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CONCLUSIONS

As a result of the background study, naturally occurring radionuclides have been identified in rock, soils and groundwater samples at the Santa Susana Field Laboratory. These natural radionuclides comprise the background radioactivity in Facility groundwater samples. Naturally occurring radionuclides have not previously been documented in geologic formations present at the Facility. However, in general, naturally occurring radionuclides are known to be components of sedimentary deposits such as the Chatsworth Formation which composes the primary groundwater system at the Facility.

The predominant natural radionuclides identified in the Chatsworth Formation and alluvial soils present at the Facility include potassium, uranium and thorium. Of these radionuclides, only uranium is significantly soluble in water. Uranium is the predominant radioactive material found in Shallow Zone and Chatsworth Formation groundwater at the Facility. Specifically, ^{238}U and decay products of the ^{238}U series have been detected in groundwater samples, in addition to ^{228}Ra, a decay product of the ^{232}Th series. In terms of activity, ^{238}U and ^{234}U are the predominant radioisotopes in both Shallow Zone and Chatsworth Formation samples.

Drinking water standards for radioactivity and radionuclide concentrations were not exceeded in any of the groundwater samples collected.

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Man-made radionuclides were not detected in any of the rock, soil, or groundwater samples collected.

As a result of the natural radionuclide study, general conclusions can be made regarding background radioactivity in, rock formations, soils, and groundwater occurring at the Facility. The ranges of values determined during the study are presented below. These values include analytical error (Tables 6 and 7):

	Range of Gross Alpha Radioactivity	Range of Gross Beta Radioactivity
Chatsworth Formation	1.70 - 12.28 pCi/g	23.99 - 45.61 pCi/g
Soils	2.00 - 10.32 pCi/g	20.52 - 32.42 pCi/g
Shallow Zone Groundwater	2.03 - 14.62 pCi/l	0.75 - 8.10 pCi/l
Chatsworth Formation Groundwater	-0.48 - 8.26 pCi/l	0.32 - 9.71 pCi/l

These background values can be used in comparison with future radioactivity data generated for rock, soil and groundwater samples collected at the Facility. Because of variations in laboratory procedures and in the types of analyses used, such comparisons, and comparisons with previously existing data will not show exact agreement. However, general agreement in terms of the radioactivity identified should be observed.

If soil or groundwater samples collected during future investigations exhibit radioactivity elevated beyond expected background levels, further evaluation of radiological parameters should be performed. The goal of such

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an evaluation would be to determine whether natural emitters or man-made radionuclides contribute to elevated levels of radioactivity. The evaluation would include analyses for gamma radiation. Isotopic uranium analyses should be performed on samples with elevated gross alpha radioactivity. Samples with elevated gross beta radioactivity should be analyzed for strontium-90. If natural emitters are determined to be sources of radioactivity measured in samples, then that data can be used to update the expected range of background radioactivity at the Facility.

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TABLES

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TABLE 1

SUMMARY OF ROCK FORMATION AND SOIL SAMPLE COLLECTION

Sample Identifier	Date Sampled	Sample Description	Sample Location Description
NE-1	10/17/89	SANDSTONE	Area IV, Approximately 25 feet south of well RD-22; directly above eroded siltstone layer
NE-2	10/17/89	SANDY CLAY	Area IV, Approximately 100 feet south of well RD-13; top of graded area, below large oak
NE-3	10/17/89	SANDY SILT	Area II, Approximately 5 feet southeast of well RS-22
NE-4	10/17/89	SILTSTONE	Outside NE site boundary, along Black Canyon Road
NE-5	10/17/89	SANDSTONE	Area I, near Facility front gate, approximately 50 feet east of utility overhead line, in cut-face boundary of south parking lot
NE-6	10/17/89	SANDSTONE	Area I, 100 feet west of well WS-6, sandstone at top of wood stairs
NE-7	10/17/89	SILTSTONE	Area II, 50 feet behind Hazardous Waste Storage office in siltstone cut.
NE-7A*	10/17/89	SILTSTONE	Adjacent to sample 7
NE-8	10/18/89	SANDSTONE	Buffer Zone, between wells RD-5 and RD-6
NE-9	10/31/89	SANDY SILT	Buffer Zone, Approximately 30 feet north of well RD-5

* = Sample duplicate

Analytical Parameters = Gross Alpha and Gross Beta Radioactivity, Gamma Radiation, Radium 226, Radium 228, Isotopic Uranium, Isotopic Thorium, Polonium 210, Lead 210.

NOTE: Analyses performed by United States Testing Company, Inc., Richland Division.

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TABLE 2

SUMMARY OF GROUNDWATER SAMPLE COLLECTION

Well Identifier	Date Sampled	Radiological Parameters	Well Location
SH-11	10/17/89	GAB, Gamma	Area III, ECL
	10/31/89	GAB, Gamma, Radium 226, Iso Uranium, Iso Thorium, Po-210, Pb-210	
RS-5	10/19/89	GAB, Gamma	Area I, along Area I Road, between Peremeter Pond and RI Pond
	10/31/89	GAB, Gamma, Radium 226, Iso Uranium, Iso Thorium, Po-210, Pb-210	
RS-28	10/19/89	GAB, Gamma	Area IV, Near Building 59
	11/01/89	GAB, Gamma, Radium 226, Iso Uranium, Iso Thorium, Po-210, Pb-210	
RD-6	10/18/89	GAB, Gamma	Buffer Zone, west side
	10/31/89	GAB, Gamma, Radium 226, Iso Uranium, Iso Thorium, Po-210, Pb-210	
RD-14	10/18/89	GAB, Gamma	Area IV, northwest of Control Center
	10/31/89	GAB, Gamma, Radium 226, Iso Uranium, Iso Thorium, Po-210, Pb-210	

GAB = Gross Alpha and Gross Beta Radioactivity
Gamma = Gamma emitting radionuclides
Iso Uranium = Isotopic Uranium
Iso Thorium = Isotopic Thorium
Po-210 = Polonium 210
Pb-210 = Lead 210

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TABLE 2 (continued)

SUMMARY OF GROUNDWATER SAMPLE COLLECTION

Well Identifier	Date Sampled	Radiological Parameters	Well Location
WS-13	10/17/89	GAB, Gamma	Area II, Near north boundary of site, northeast of swimming pool
	11/01/89	GAB, Gamma, Radium 226, Iso Uranium, Iso Thorium, Po-210, Pb-210	
WS-13 D	10/17/89	GAB, Gamma	Area II, Near north boundary of site, northeast of swimming pool
	11/01/89	GAB, Gamma, Radium 226, Iso Uranium, Iso Thorium, Po-210, Pb-210	
OS-16	10/19/89	GAB, Gamma	Northeast of site, south of Woolsey Canyon Road
	11/01/89	GAB, Gamma, Radium 226, Iso Uranium, Iso Thorium, Po-210, Pb-210	
OS-16 D	10/19/89	GAB, Gamma	Northeast of site, south of Woolsey Canyon Road
	11/01/89	GAB, Gamma, Radium 226, Iso Uranium, Iso Thorium, Po-210, Pb-210	
OS-21	10/19/89	GAB, Gamma	Southwest of site
	11/01/89	GAB, Gamma, Radium 226, Iso Uranium, Iso Thorium, Po-210, Pb-210	

GAB = Gross Alpha and Gross Beta Radioactivity
Gamma = Gamma emitting radionuclides
Iso Uranium = Isotopic Uranium
Iso Thorium = Isotopic Thorium
Po-210 = Polonium 210
Pb-210 = Lead 210

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TABLE 3

DESCRIPTION OF ANALYTICAL METHODS

Analytical Parameter	Analytical Method
Gross Alpha and Gross Beta Radioactivity	EPA 900.0[1]
Gamma Emitting Radionuclides	EPA 901.1[1]
Radium-226, Radium-228	EPA 900.1[1]
Isotopic Uranium	EPA 908.0[1]
Isotopic Thorium	Ion exchange separation, alpha count[2]
Polonium-210	Spontaneous deposition, alpha count[2]
Lead-210	Beta count of bismuth daughter product[2]

[1] EPA - 600/4-80-032 Prescribed Procedures Measurement of Radioactivity in Drinking Water, U.S. E.P.A., August 1980.

[2] Description of analytical procedure.

TABLE 4

SUMMARY OF RESULTS FOR GROSS ALPHA AND GROSS BETA RADIOACTIVITY IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	DATE SAMPLED	CONCENTRATION (picocuries per gram) GROSS ALPHA RADIOACTIVITY	GROSS BETA RADIOACTIVITY	SAMPLE DESCRIPTION
NE-1	10/17/89	6.32 ± 2.82	32.2 ± 4.97	SANDSTONE
NE-2	10/17/89	7.24 ± 3.08	27.0 ± 4.46	SANDY CLAY SOIL
NE-3	10/17/89	5.49 ± 2.75	27.9 ± 4.52	SANDY SILT SOIL
NE-4	10/17/89	4.84 ± 2.40	39.7 ± 5.78	SILTSTONE
NE-5	10/17/89	3.93 ± 2.23	29.1 ± 4.68	SANDSTONE
NE-6	10/17/89	6.60 ± 2.82	33.3 ± 5.21	SANDSTONE
NE-7	10/17/89	9.01 ± 3.27	39.8 ± 5.81	SILTSTONE
NE-7A*	10/17/89	8.06 ± 3.19	38.2 ± 5.62	SILTSTONE
NE-8	10/18/89	8.60 ± 3.27	28.6 ± 4.61	SANDSTONE
NE-9	10/31/89	4.43 ± 2.43	24.7 ± 4.18	SANDY SILT SOIL

(*) = Sample duplicate

NOTE: Sample analyses performed by United States Testing Company, Inc., Richland Division.

TABLE 5

SUMMARY OF RESULTS FOR GROSS ALPHA AND GROSS BETA RADIOACTIVITY IN BACKGROUND GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	CONCENTRATION (picocuries per liter) GROSS ALPHA RADIOACTIVITY	GROSS BETA RADIOACTIVITY	SAMPLE FILTRATION
SH-11	10/17/89	5.23 ± 2.97	2.43 ± 1.68	F
	10/31/89	10.4 ± 6.06	6.96 ± 2.82	UF
		9.57 ± 5.05	2.95 ± 2.45	F
RS-5	10/19/89	7.79 ± 3.55	3.17 ± 1.85	F
	10/31/89	37.2 ± 11.1	8.32 ± 3.02	UF
		6.15 ± 4.71	5.30 ± 2.80	F
RS-28	10/19/89	7.07 ± 3.03	3.53 ± 1.79	F
	11/01/89	7.38 ± 3.45	7.03 ± 2.84	UF
		4.62 ± 2.59	4.76 ± 2.59	F
RD-6	10/18/89	2.10 ± 1.98	5.16 ± 1.99	F
	10/31/89	4.90 ± 3.98	6.03 ± 2.77	UF
		3.11 ± 2.42	6.22 ± 2.79	F
RD-14	10/18/89	4.83 ± 2.48	1.97 ± 1.65	F
	10/31/89	6.33 ± 3.05	5.15 ± 2.63	UF
		5.27 ± 2.62	5.01 ± 2.62	F

(*) = Sample duplicate
1/ Indicates a result less than the overall laboratory error
F = Sample filtered prior to analysis
UF = Sample unfiltered prior to analysis

NOTE: Sample Analyses performed by United States Testing Company, Inc., Richland Division.

TABLE 5 (continued)

SUMMARY OF RESULTS FOR GROSS ALPHA AND GROSS BETA RADIOACTIVITY IN AREA IV GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	CONCENTRATION (picocuries per liter) GROSS ALPHA RADIOACTIVITY	GROSS BETA RADIOACTIVITY	SAMPLE FILTRATION
WS-13	10/17/89	4.01 ± 2.45	3.82 ± 1.86	F
WS-13 D*	10/17/89	2.98 ± 2.24	3.90 ± 1.90	F
	11/01/89	1.68[1/] ± 1.92	5.77 ± 2.76	UF
		1.69[1/] ± 1.73	5.82 ± 2.75	F
OS-16	10/19/89	5.54 ± 2.72	5.04 ± 1.99	F
	11/01/89	2.57 ± 2.20	6.75 ± 2.92	UF
		4.39 ± 2.73	6.73 ± 2.59	F
OS-16 D*	10/19/89	5.11 ± 2.59	4.27 ± 1.92	F
	11/01/89	4.05 ± 2.65	4.29 ± 2.59	UF
		5.06 ± 2.95	6.99 ± 2.72	F
OS-21	10/19/89	1.08[1/] ± 1.56	2.91 ± 1.78	F
	11/01/89	2.82 ± 2.18	6.83 ± 2.83	UF
		1.42[1/] ± 1.90	3.56 ± 2.52	F

(*) = Sample duplicate
[1/] Indicates a result less than the overall laboratory error.
F = Sample filtered prior to analysis
UF = Sample unfiltered prior to analysis

NOTE: Sample Analyses performed by United States Testing Company, Inc., Richland Division.

TABLE 6

MEAN AND RANGE OF RESULTS

ROCK AND SOIL SAMPLES

Sample Description		Gross Alpha Radioactivity (pCi/g)	Gross Beta Radioactivity (pCi/g)	Potassium-40 (pCi/g)	Uranium-238 (pCi/g)	Uranium-234 (pCi/g)	Thorium-232 (pCi/g)
SANDSTONE	**(N=4)**						
Mean		6.36	30.8	24.2	1.26	1.26	1.35
Range	low:	3.93 ± 2.23	28.6 ± 4.61	21.4 ± 2.91	0.830 ± 0.122	0.852 ± 0.126	1.14 ± 0.141
	high:	8.60 ± 3.27	33.3 ± 5.21	26.5 ± 2.92	1.55 ± 0.196	1.53 ± 0.208	1.62 ± 0.186
SILTSTONE	**(N=3)**						
Mean		7.30	39.2	25.9	1.48	1.36	1.70
Range	low:	4.84 ± 2.40	38.2 ± 5.62	24.7 ± 2.81	1.29 ± 0.177	1.24 ± 0.172	1.18 ± 0.174
	high:	9.01 ± 3.27	39.8 ± 5.81	26.6 ± 2.88	1.74 ± 0.219	1.45 ± 0.193	2.28 ± 0.250
SOIL	**(N=3)**						
Mean		5.72	26.5	22.2	1.10	1.10	1.66
Range	low:	4.43 ± 2.43	24.7 ± 4.18	21.1 ± 2.32	0.771 ± 0.118	0.688 ± 0.113	1.45 ± 0.169
	high:	7.24 ± 3.08	27.9 ± 4.52	23.5 ± 2.78	1.29 ± 0.175	1.33 ± 0.188	2.03 ± 0.227

N = Number of samples
pCi/g = picocuries per gram

NOTE: Analytical error has not been factored into mean

HDMSP00010203

TABLE 7

MEAN AND RANGE OF RESULTS

GROUNDWATER SAMPLES

Sample Description		Gross Alpha Radioactivity (pCi/l)	Gross Beta Radioactivity (pCi/l)	Radium-226 (pCi/l)	Radium-228 (pCi/l)	Uranium-238 (pCi/l)	Uranium-234 (pCi/l)
SHALLOW ZONE GROUNDWATER							
N		6	6	3	3	3	3
Mean		6.74	3.69	0.0957	0.896	4.23	4.56
Range	low:	4.62 ± 2.59	2.43 ± 1.68	0.0035 ± 0.459	0.686 ± 0.540	3.42 ± 0.585	3.29 ± 0.577
	high:	9.57 ± 5.05	5.30 ± 2.80	0.254 ± 0.0976	1.16 ± 4.87	5.04 ± 0.741	5.81 ± 0.830
CHATSWORTH FORMATION GROUNDWATER							
N		13	13	6	6	6	6
Mean		3.58	4.72	0.789	1.525	1.61	2.00
Range	low:	1.08 ± 1.56	1.97 ± 1.65	0.484 ± 0.152	0.859 ± 0.531	0.710 ± 0.193	0.892 ± 0.227
	high:	5.54 ± 2.72	6.99 ± 2.72	1.09 ± 0.230	2.32 ± 0.729	2.57 ± 0.441	2.63 ± 0.453

N = Number of samples
pCi/l = picocuries per liter

NOTE: Analytical error has not been factored into mean
Results reflect filtered samples only

HDMSP00010204

TABLE 8

OVERALL PRECISION OF GROSS ALPHA AND GROSS BETA RADIOACTIVITY MEASUREMENTS

Sample Identifier	Sample Type	Date Sampled	Gross Alpha		Gross Beta		RPD (percent)	
			D-1	D-2	D-1	D-2	Gross Alpha	Gross Beta
NE-7, NE-7A	Siltstone	10/17/89	9.01	8.06	39.8	38.2	11	4
WS-13, WS-13D	Groundwater Chatsworth Formation	10/17/89	4.01	2.98	3.82	3.90	30	2
OS-16, OS-16D	Groundwater Chatsworth Formation	10/19/89	5.54	5.11	5.04	4.27	8	17
		11/01/89	4.39	5.06	6.73	6.99	14	4

RPD = Relative Percent Difference

$$RPD = 2 \frac{(D_1 - D_2)}{(D_1 + D_2)} 100$$

where D_1 = Sample result (pCi/l)
D_2 = Sample duplicate result (pCi/l)

HDMSP00010205

APPENDIX A

HDMSP00010206

APPENDIX A

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HDMSP00010215

APPENDIX B

HDMSP00010216

TABLE B-1

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	SAMPLE DESCRIPTION	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)
NE-1	Sandstone	10/17/89	Gross Alpha Radioactivity	6.32 ± 2.82
			Gross Beta Radioactivity	32.2 ± 4.97
			Potassium-40 (Gamma Scan)	26.5 ± 2.92
			Cesium-137 (Gamma Scan)	0.0677 ± 0.0304
			Lead-212 (Gamma Scan)	0.848 ± 0.105
			Lead-214 (Gamma Scan)	0.994 ± 0.137
			Lead-210	1.31 ± 0.692
			Polonium-210	1.35 ± 0.199
			Uranium-234	1.53 ± 0.208
			Uranium-235	0.0662 ± 0.0312
			Uranium-238	1.53 ± 0.206
			Thorium-228	1.42 ± 0.166
			Thorium-230	1.45 ± 0.165
			Thorium-232	1.30 ± 0.151
			Radium-226	0.877 ± 0.127
			Radium-228	0.809 ± 0.175

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count

HDMSP00010217

TABLE B-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	SAMPLE DESCRIPTION	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)
NE-2	Sandy Clay Soil	10/17/89	Gross Alpha Radioactivity	7.24 ± 3.08
			Gross Beta Radioactivity	27.0 ± 4.46
			Potassium-40 (Gamma Scan)	21.1 ± 2.32
			Cesium-137 (Gamma Scan)	0.0578 ± 0.0264
			Lead-212 (Gamma Scan)	1.42 ± 0.155
			Lead-214 (Gamma Scan)	0.849 ± 0.109
			Lead-210	0.818[1/] ± 0.870
			Polonium-210	0.773 ± 0.121
			Uranium-234	0.688 ± 0.113
			Uranium-235	0.0319 ± 0.0213
			Uranium-238	0.771 ± 0.118
			Thorium-228	1.72 ± 0.198
			Thorium-230	1.14 ± 0.140
			Thorium-232	1.50 ± 0.174
			Radium-226	0.799 ± 0.108
			Radium-228	1.32 ± 0.200

[1/]Indicates a result less than the overall laboratory error
[2/]Negative sign indicates sample count less than instrument background count

HDMSP00010218

TABLE B-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	SAMPLE DESCRIPTION	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)
NE-3	Sandy Silt Soil	10/17/89	Gross Alpha Radioactivity	5.49 ± 2.75
			Gross Beta Radioactivity	27.9 ± 4.52
			Potassium-40 (Gamma Scan)	22.0 ± 2.39
			Cesium-137 (Gamma Scan)	0.126 ± 0.0278
			Lead-212 (Gamma Scan)	1.21 ± 0.131
			Lead-214 (Gamma Scan)	0.940 ± 0.115
			Lead-210	1.05 ± 0.738
			Polonium-210	1.28 ± 0.165
			Uranium-234	1.27 ± 0.175
			Uranium-235	0.0568 ± 0.0281
			Uranium-238	1.29 ± 0.175
			Thorium-228	1.72 ± 0.199
			Thorium-230	1.30 ± 0.154
			Thorium-232	1.45 ± 0.169
			Radium-226	0.887 ± 0.114
			Radium-228	1.25 ± 0.182

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count

HDMSP00010219

TABLE B-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	SAMPLE DESCRIPTION	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)
NE-4	Siltstone	10/17/89	Gross Alpha Radioactivity	4.84 ± 2.40
			Gross Beta Radioactivity	39.7 ± 5.78
			Potassium-40 (Gamma Scan)	26.4 ± 2.82
			Cesium-137 (Gamma Scan)	0.00902[1/] ± 0.0227
			Lead-212 (Gamma Scan)	1.63 ± 0.176
			Lead-214 (Gamma Scan)	1.36 ± 0.157
			Lead-210	1.30 ± 0.959
			Polonium-210	1.77 ± 0.217
			Uranium-234	1.40 ± 0.192
			Uranium-235	0.0595 ± 0.0292
			Uranium-238	1.42 ± 0.192
			Thorium-228	2.04 ± 0.231
			Thorium-230	1.63 ± 0.188
			Thorium-232	2.28 ± 0.250
			Radium-226	1.23 ± 0.146
			Radium-228	1.80 ± 0.235

[1/]Indicates a result less than the overall laboratory error
[2/]Negative sign indicates sample count less than instrument background count

HDMSP00010220

TABLE B-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	SAMPLE DESCRIPTION	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)
NE-5	Sandstone	10/17/89	Gross Alpha Radioactivity	3.93 ± 2.23
			Gross Beta Radioactivity	29.1 ± 4.68
			Potassium-40 (Gamma Scan)	21.4 ± 2.41
			Cesium-137 (Gamma Scan)	-0.00332[1/ 2/] ± 0.0268
			Lead-212 (Gamma Scan)	0.969 ± 0.118
			Lead-214 (Gamma Scan)	0.929 ± 0.127
			Lead-210	1.47 ± 0.780
			Polonium-210	1.06 ± 0.149
			Uranium-234	1.50 ± 0.193
			Uranium-235	0.0936 ± 0.0339
			Uranium-238	1.55 ± 0.196
			Thorium-228	1.31 ± 0.156
			Thorium-230	1.46 ± 0.166
			Thorium-232	1.34 ± 0.154
			Radium-226	0.849 ± 0.121
			Radium-228	1.02 ± 0.177

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count

HDMSP00010221

TABLE B-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	SAMPLE DESCRIPTION	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)
NE-6	Sandstone	10/17/89	Gross Alpha Radioactivity	6.60 ± 2.82
			Gross Beta Radioactivity	33.3 ± 5.21
			Potassium-40 (Gamma Scan)	26.4 ± 3.28
			Cesium-137 (Gamma Scan)	0.643 ± 0.111
			Lead-212 (Gamma Scan)	2.23 ± 0.262
			Lead-214 (Gamma Scan)	1.02 ± 0.185
			Lead-210	2.23 ± 0.708
			Polonium-210	1.31 ± 0.174
			Uranium-234	1.17 ± 0.175
			Uranium-235	0.0350 ± 0.0245
			Uranium-238	1.14 ± 0.169
			Thorium-228	1.31 ± 0.162
			Thorium-230	1.35 ± 0.161
			Thorium-232	1.14 ± 0.141
			Radium-226	1.06 ± 0.179
			Radium-228	1.39 ± 0.324

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count

HDMSP00010222

TABLE B-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	SAMPLE DESCRIPTION	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)
NE-7	Siltstone	10/17/89	Gross Alpha Radioactivity	9.01 ± 3.27
			Gross Beta Radioactivity	39.8 ± 5.81
			Potassium-40 (Gamma Scan)	24.7 ± 2.81
			Cesium-137 (Gamma Scan)	0.0169[1/] ± 0.0342
			Lead-212 (Gamma Scan)	1.86 ± 0.208
			Lead-214 (Gamma Scan)	1.14 ± 0.156
			Lead-210	2.20 ± 0.804
			Polonium-210	1.48 ± 0.185
			Uranium-234	1.24 ± 0.172
			Uranium-235	0.0300 ± 0.0219
			Uranium-238	1.29 ± 0.177
			Thorium-228	1.87 ± 0.224
			Thorium-230	1.40 ± 0.171
			Thorium-232	1.64 ± 0.195
			Radium-226	1.03 ± 0.146
			Radium-228	1.70 ± 0.297

[1/]Indicates a result less than the overall laboratory error
[2/]Negative sign indicates sample count less than instrument background count

HDMSP00010223

TABLE B-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	SAMPLE DESCRIPTION	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)
NE-7A*	Siltstone	10/17/89	Gross Alpha Radioactivity	8.06 ± 3.19
			Gross Beta Radioactivity	38.2 ± 5.62
			Potassium-40 (Gamma Scan)	26.6 ± 2.88
			Cesium-137 (Gamma Scan)	-0.0367[1/ 2/] ± 0.0293
			Lead-212 (Gamma Scan)	1.80 ± 0.195
			Lead-214 (Gamma Scan)	1.17 ± 0.144
			Lead-210	1.70 ± 0.919
			Polonium-210	1.55 ± 0.199
			Uranium-234	1.45 ± 0.193
			Uranium-235	0.0512 ± 0.0266
			Uranium-238	1.74 ± 0.219
			Thorium-228	1.21 ± 0.189
			Thorium-230	1.09 ± 0.164
			Thorium-232	1.18 ± 0.174
			Radium-226	1.18 ± 0.146
			Radium-228	1.71 ± 0.240

(*) = Sample duplicate

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count

HDMSP00010224

TABLE B-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	SAMPLE DESCRIPTION	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)
NE-8	Sandstone	10/18/89	Gross Alpha Radioactivity	8.60 ± 3.27
			Gross Beta Radioactivity	28.6 ± 4.61
			Potassium-40 (Gamma Scan)	22.4 ± 2.44
			Cesium-137 (Gamma Scan)	0.142 ± 0.0288
			Lead-212 (Gamma Scan)	1.31 ± 0.143
			Lead-214 (Gamma Scan)	0.691 ± 0.0930
			Lead-210	1.48 ± 0.799
			Polonium-210	1.01 ± 0.139
			Uranium-234	0.852 ± 0.126
			Uranium-235	0.0201 ± 0.0166
			Uranium-238	0.830 ± 0.122
			Thorium-228	1.82 ± 0.210
			Thorium-230	1.13 ± 0.141
			Thorium-232	1.62 ± 0.186
			Radium-226	0.659 ± 0.0928
			Radium-228	1.33 ± 0.195

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count

HDMSP00010225

TABLE B-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN SOIL AND ROCK SAMPLES

SAMPLE IDENTIFIER	SAMPLE DESCRIPTION	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)
NE-9	Sandy Silt Soil	10/31/89	Gross Alpha Radioactivity	4.43 ± 2.43
			Gross Beta Radioactivity	24.7 ± 4.18
			Potassium-40 (Gamma Scan)	23.5 ± 2.78
			Cesium-137 (Gamma Scan)	0.0216[1/] ± 0.0376
			Lead-212 (Gamma Scan)	0.973 ± 0.130
			Lead-214 (Gamma Scan)	0.718 ± 0.127
			Lead-210	1.11 ± 0.494
			Polonium-210	1.33 ± 0.175
			Uranium-234	1.33 ± 0.188
			Uranium-235	0.0272 ± 0.0264
			Uranium-238	1.25 ± 0.180
			Thorium-228	2.16 ± 0.244
			Thorium-230	1.52 ± 0.179
			Thorium-232	2.03 ± 0.227
			Radium-226	0.782 ± 0.140
			Radium-228	1.31 ± 0.246

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count

HDMSP00010226

APPENDIX C

HDMSP00010227

TABLE C-1

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
SH-11	10/17/89	Gross Alpha Radioactivity	5.23 ± 2.97	F
		Gross Beta Radioactivity	2.43 ± 1.68	F
		Cesium-137 (Gamma Scan)	2.26[1/] ± 4.55	F
	10/31/89	Gross Alpha Radioactivity	10.4 ± 6.06	UF
			9.57 ± 5.05	F
		Gross Beta Radioactivity	6.96 ± 2.82	UF
			2.95 ± 2.45	F
		Cesium-137 (Gamma Scan)	-0.621[1/ 2/] ± 5.25	UF
			3.24[1/] ± 4.18	F
		Uranium-234	3.91 ± 0.702	UF
			3.29 ± 0.577	F
		Uranium-235	0.144 ± 0.127	UF
			0.0843[1/] ± 0.0848	F
		Uranium-238	2.94 ± 0.608	UF
			3.42 ± 0.585	F
		Radium-226	0.425 ± 0.120	UF
			0.254 ± 0.0976	F
		Radium-228	1.23 ± 0.493	UF
			0.842 ± 0.405	F
		Polonium-210	0.549 ± 0.0934	UF
			0.175 ± 0.0486	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010228

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
SH-11 (cont'd)	10/31/89	Thorium-228	0.575 ± 0.333	UF
			-0.0205[1/ 2/] ± 0.0239	F
		Thorium-230	0.284 ± 0.137	UF
			0.00785[1/] ± 0.00789	F
		Thorium-232	0.583 ± 0.201	UF
			0.00981[1/] ± 0.0104	F
		Lead-210	3.35 ± 0.643	UF
			0.427 ± 0.421	F
RS-5	10/19/89	Gross Alpha Radioactivity	7.79 ± 3.55	F
		Gross Beta Radioactivity	3.17 ± 1.85	F
	10/31/89	Gross Alpha Radioactivity	37.2 ±11.1	UF
			6.15 ± 4.71	F
		Gross Beta Radioactivity	8.32 ± 3.01	UF
			5.30 ± 2.80	F
		Cesium-137 (Gamma Scan)	-2.73[1/ 2/] ± 4.72	UF
			-2.54[1/ 2/] ± 5.37	F
		Uranium-234	5.73 ± 0.988	UF
			5.81 ± 0.830	F
		Uranium-235	0.241 ± 0.202	UF
			0.0883 ± 0.0823	F
		Uranium-238	5.83 ± 0.991	UF
			5.04 ± 0.741	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010229

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per gram)	SAMPLE HANDLING
RS-5 (cont'd)	10/31/89	Radium-226	0.359 ± 0.124	UF
			0.00350[1/ 2/] ± 0.0459	F
		Radium-228	2.19 ± 0.657	UF
			1.16 ± 0.487	F
		Polonium-210	0.719 ± 0.134	UF
			0.0526 ± 0.0241	F
		Thorium-228	1.20 ± 0.463	UF
			0.0345[1/] ± 0.0346	F
		Thorium-230	0.917 ± 0.309	UF
			0.00827[1/] ± 0.0117	F
		Thorium-232	1.68 ± 0.440	UF
			0.0393 ± 0.0202	F
		Lead-210	3.87 ± 0.682	UF
			0.319[1/] ± 0.396	F
RS-28	10/19/89	Gross Alpha Radioactivity	7.07 ± 3.03	F
		Gross Beta Radioactivity	3.53 ± 1.79	F
		Cesium-137 (Gamma Scan)	2.48[1/] ± 4.22	F
	11/01/89	Gross Alpha Radioactivity	7.38 ± 3.45	UF
			4.62 ± 2.59	F
		Gross Beta Radioactivity	7.03 ± 2.84	UF
			4.76 ± 2.59	F
		Cesium-137 (Gamma Scan)	-1.27[1/ 2/] ± 4.39	UF
			1.77 ± 3.90	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010230

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
RS-28 (cont'd)	11/01/89	Uranium-234	4.59 ± 0.181	F
		Uranium-235	0.153 ± 0.0139	F
		Uranium-238	4.24 ± 0.147	F
		Radium-226	0.105 ± 0.0854	UF
			0.0296[1/] ± 0.0596	F
		Radium-228	0.726 ± 0.669	UF
			0.686 ± 0.540	F
		Polonium-210	0.140 ± 0.0419	UF
			0.0320 ± 0.0187	F
		Thorium-228	0.586 ± 0.0930	UF
			0.0222[1/] ± 0.0283	F
		Thorium-230	0.147 ± 0.0377	UF
			0.00580[1/] ± 0.0102	F
		Thorium-232	0.662 ± 0.0961	UF
			0.00193[1/] ± 0.00387	F
		Lead-210	1.38 ± 0.429	UF
			0.199[1/] ± 0.310	F
RD-6	10/18/89	Gross Alpha Radioactivity	2.10 ± 1.98	F
		Gross Beta Radioactivity	5.16 ± 1.99	F
		Cesium-137 (Gamma Scan)	-4.36[1/ 2/] ± 4.83	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010231

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
RD-6 (cont'd)	10/31/89	Gross Alpha Radioactivity	4.90 ± 3.98	UF
			3.11 ± 2.42	F
		Gross Beta Radioactivity	6.03 ± 2.77	UF
			6.22 ± 2.79	F
		Cesium-137 (Gamma Scan)	1.96[1/] ± 2.90	UF
			0.942[1/] ± 4.43	F
		Uranium-234	1.20 ± 0.302	UF
			0.892 ± 0.227	F
		Uranium-235	0.154 ± 0.111	UF
			0.0143[1/] ± 0.0508	F
		Uranium-238	1.08 ± 0.274	UF
			0.710 ± 0.193	F
		Radium-226	1.23 ± 0.268	UF
			0.852 ± 0.202	F
		Radium-228	2.56 ± 0.806	UF
			2.32 ± 0.729	F
		Polonium-210	0.0461 ± 0.0235	UF
			0.0258 ± 0.0183	F
		Thorium-228	0.0714 ± 0.0323	UF
			0.0428 ± 0.0360	F
		Thorium-230	0.00185[1/] ± 0.00642	UF
			0.00196[1/] ± 0.00392	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010232

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
RD-6 (cont'd)		Thorium-232	0.00185[1/] ± 0.00371	UF
			0.00[1/] ± 0.00588	F
		Lead-210	0.136[1/] ± 0.348	UF
			0.311[1/] ± 0.351	F
RD-14	10/18/89	Gross Alpha Radioactivity	4.83 ± 2.48	F
		Gross Beta Radioactivity	1.97 ± 1.65	F
		Cesium-137 (Gamma Scan)	4.41[1/] ± 4.80	F
	10/31/89	Gross Alpha Radioactivity	6.33 ± 3.05	UF
			5.27 ± 2.62	F
		Gross Beta Radioactivity	5.15 ± 2.63	UF
			5.01 ± 2.62	F
		Cesium-137 (Gamma Scan)	-3.42[1/ 2/] ± 4.58	UF
			-3.10[1/ 2/] ± 5.29	F
		Uranium-234	2.99 ± 0.539	UF
			2.63 ± 0.453	F
		Uranium-235	0.0662[1/] ± 0.0881	UF
			0.131 ± 0.0889	F
		Uranium-238	2.68 ± 0.495	UF
			2.57 ± 0.441	F
		Radium-226	0.469 ± 0.137	UF
			0.585 ± 0.160	F
		Radium-228	0.747 ± 0.391	UF
			0.901 ± 0.492	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010233

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
RD-14 (cont'd)	10/31/89	Polonium-210	0.172 ± 0.0499	UF
			0.139 ± 0.0424	F
		Thorium-228	0.0404 ± 0.0288	UF
			0.0406 ± 0.0347	F
		Thorium-230	0.00388[1/] ± 0.00550	UF
			0.00[1/] ± 0.0142	F
		Thorium-232	0.0136 ± 0.0104	UF
			0.00410[1/] ± 0.0153	F
		Lead-210	1.12 ± 0.416	UF
			0.966 ± 0.409	
WS-13	10/17/89	Gross Alpha Radioactivity	4.01 ± 2.45	F
		Gross Beta Radioactivity	3.82 ± 1.86	F
		Cesium-137 (Gamma Scan)	2.65[1/] ± 3.78	F
WS-13 D*	10/17/89	Gross Alpha Radioactivity	2.98 ± 2.24	F
		Gross Beta Radioactivity	3.90 ± 1.90	F
		Cesium-137 (Gamma Scan)	1.44[1/] ± 5.00	F
	11/01/89	Gross Alpha Radioactivity	1.68[1/] ± 1.92	UF
			1.69[1/] ± 1.73	F
		Gross Beta Radioactivity	5.77 ± 2.76	UF
			5.82 ± 2.75	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010234

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
WS-13 D* (cont'd)	11/01/89	Cesium-137 (Gamma Scan)	1.57[1/] ± 4.11	UF
			2.59[1/] ± 5.42	F
		Uranium-234	2.01 ± 0.226	F
		Uranium-235	0.0697 ± 0.0243	F
		Uranium-238	1.31 ± 0.159	F
		Radium-226	0.487 ± 0.143	UF
			0.484 ± 0.152	F
		Radium-228	0.879 ± 0.479	UF
			0.859 ± 0.531	F
		Polonium-210	0.0533 ± 0.0250	UF
			0.0103[1/] ± 0.0135	F
		Thorium-228	0.0390 ± 0.0319	UF
			0.0906 ± 0.0387	F
		Thorium-230	0.00562[1/] ± 0.00840	UF
			0.0163 ± 0.0110	F
		Thorium-232	0.0262 ± 0.0152	UF
			0.0507 ± 0.0204	F
		Lead-210	0.718 ± 0.390	UF
			0.407 ± 0.364	F
OS-16	10/19/89	Gross Alpha Radioactivity	5.54 ± 2.72	F
		Gross Beta Radioactivity	5.04 ± 1.99	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010235

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
OS-16 (cont'd)	11/01/89	Gross Alpha Radioactivity	2.57 ± 2.20	UF
			4.39 ± 2.73	F
		Gross Beta Radioactivity	6.75 ± 2.92	UF
			6.73 ± 2.59	F
		Cesium-137 (Gamma Scan)	-3.32[1/ 2/] ± 5.87	UF
			-1.12[1/ 2/] ± 4.77	F
		Uranium-234	2.42 ± 0.275	F
		Uranium-235	0.0840 ± 0.0292	F
		Uranium-238	2.03 ± 0.237	F
		Radium-226	1.07 ± 0.239	UF
			0.968 ± 0.227	F
		Radium-228	1.94 ± 0.767	UF
			1.50 ± 0.723	F
		Polonium-210	0.0357 ± 0.0209	UF
			0.0265 ± 0.0216	F
		Thorium-228	0.109 ± 0.0410	UF
			0.0319[1/] ± 0.0352	F
		Thorium-230	0.00534[1/] ± 0.00618	UF
			0.00942[1/] ± 0.00947	F
		Thorium-232	0.0889 ± 0.0265	UF
			0.00[1/] ± 0.00707	F
		Lead-210	0.574 ± 0.367	UF
			0.501 ± 0.336	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010236

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
OS-16 D*	10/19/89	Gross Alpha Radioactivity	5.11 ± 2.59	F
		Gross Beta Radioactivity	4.27 ± 1.92	F
	11/01/89	Gross Alpha Radioactivity	4.05 ± 2.65	UF
			5.06 ± 2.95	F
		Gross Beta Radioactivity	4.29 ± 2.59	UF
			6.99 ± 2.72	F
		Cesium-137 (Gamma Scan)	3.07[1/] ± 4.38	UF
			0.386[1/] ± 4.63	F
		Uranium-234	2.48 ± 0.277	F
		Uranium-235	0.0541 ± 0.0227	F
		Uranium-238	1.99 ± 0.250	F
		Radium-226	0.993 ± 0.223	UF
			1.09 ± 0.230	F
		Radium-228	1.84 ± 0.644	UF
			1.62 ± 0.587	F
		Polonium-210	0.0960 ± 0.0313	UF
			0.0117 ± 0.0116	F
		Thorium-228	0.0456 ± 0.0274	UF
			0.0250[1/] ± 0.0297	F
		Thorium-230	0.00175[1/] ± 0.00350	UF
			0.00369[1/] ± 0.00739	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010237

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
OS-16 D* (cont'd)	11/01/89	Thorium-232	0.00[1/] ± 0.00525	UF
			0.00[1/] ± 0.00554	F
		Lead-210	0.611 ± 0.368	UF
			0.331[1/] ± 0.353	F
OS-21	10/19/89	Gross Alpha Radioactivity	1.08[1/] ± 1.56	F
		Gross Beta Radioactivity	2.91 ± 1.78	F
	11/01/89	Gross Alpha Radioactivity	2.82 ± 2.18	UF
			1.42[1/] ± 1.90	F
		Gross Beta Radioactivity	6.83 ± 2.83	UF
			3.56 ± 2.52	F
		Cesium-137 (Gamma Scan)	1.84[1/] ± 3.97	UF
			1.65[1/] ± 4.55	F
		Uranium-234	1.54 ± 0.185	F
		Uranium-235	0.0306 ± 0.0163	F
		Uranium-238	1.06 ± 0.137	F
		Radium-226	0.778 ± 0.196	UF
			0.756 ± 0.189	F
		Radium-228	1.46 ± 0.597	UF
			1.95 ± 0.704	F
		Polonium-210	0.0332 ± 0.0186	UF
			0.00463[1/] ± 0.00656	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010238

TABLE C-1 (continued)

RESULTS OF ANALYSES FOR NATURAL EMITTERS IN GROUNDWATER SAMPLES

WELL IDENTIFIER	DATE SAMPLED	RADIOLOGICAL PARAMETER	CONCENTRATION (picocuries per liter)	SAMPLE FILTRATION
OS-21 (cont'd)	11/01/89	Thorium-228	0.00[1/] ± 0.0355	UF
			0.149 ± 0.0468	F
		Thorium-230	0.00359[1/] ± 0.00509	UF
			0.0795 ± 0.0265	F
		Thorium-232	0.00[1/] ± 0.00539	UF
			0.0659 ± 0.0247	F
		Lead-210	0.376 ± 0.361	UF
			0.0370[1/] ± 0.354	F

[1/] Indicates a result less than the overall laboratory error
[2/] Negative sign indicates sample count less than instrument background count
(*) = Sample duplicate
UF = Sample unfiltered prior to analyses
F = Sample filtered prior to analyses

HDMSP00010239

HDMSP00010240

HDMSP00010241

Base from USGS Santa Susana 7.5' Quad.

Base from USGS Calabasas 7.5' Quad.

Simi Valley

Santa Susana

Santa Susana Knolls

Chatsworth Pk

Chatsworth Lake Manor

Burro Flats

Lakeside Park

San Fernando Valley

VENTURA CO.
LOS ANGELES CO.

SSFL PROPERTY LINE

SSFL AREA BOUNDARIES

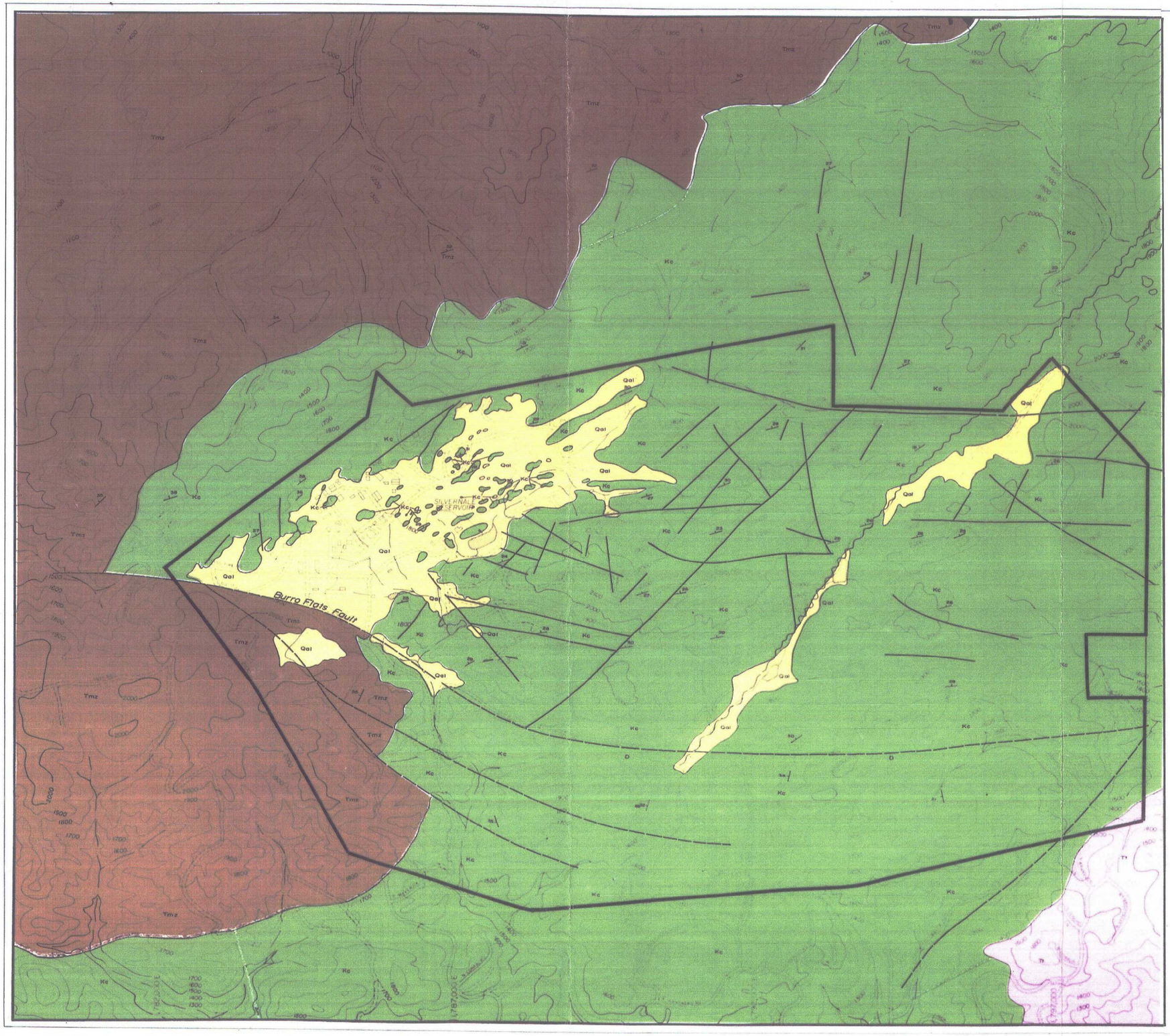
SCALE IN FEET

0 2000 4000

ROCKWELL INTERNATIONAL CORPORATION
ROCKETDYNE DIVISION
SANTA SUSANA FIELD LABORATORY

FACILITY LOCATION MAP

GROUNDWATER RESOURCES CONSULTANTS, INC.
CONSULTANTS IN HYDROGEOLOGY
TUCSON, ARIZONA 8640M-77 FIGURE 1



EXPLANATION

TERTIARY QUATERNARY

- Qal — QUATERNARY ALLUVIUM, UNCONSOLIDATED MIXTURE OF SAND, SILT, AND CLAY

UNCONFORMITY

- Tt — TOPANGA FORMATION, BEDDED MARINE SANDSTONE AND CONGLOMERATE
- Tmz — MARTINEZ FORMATION, FOSSILIFEROUS MARINE SANDSTONES AND SILTSTONES

UNCONFORMITY

CRETACEOUS

- Kc — CHATSWORTH FORMATION, MARINE SANDSTONE WITH INTERBEDDED SILTSTONES AND CLAYSTONES AND MINOR CONGLOMERATIC BEDS

BOUNDARY OF SSFL FACILITY

TRACE OF FAULT
DASHED WHERE INFERRED OR CONCEALED BY DEPOSITS OF RECENT AGE

SHEAR ZONE
GOUGE AND CONTORTED BEDDING

TRACE OF JOINT OR FRACTURE
BASED ON PHOTOGEOLOGY

CONTACT

24 STRIKE AND DIP OF BEDS

EPHEMERAL DRAINAGES

FEET

ROCKWELL INTERNATIONAL CORPORATION
ROCKETDYNE DIVISION
SANTA SUSANA FIELD LABORATORY

GEOLOGIC MAP

GROUNDWATER RESOURCES CONSULTANTS, INC.
CONSULTANTS IN HYDROGEOLOGIC
TUCSON, ARIZONA

NOVEMBER, 1987

FIGURE 2

HDMSP00010242